

LA-UR-18-29410

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Title: Tensile Testing on FFTF Irradiated Fast Reactor Cladding

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Intended for: Report

Issued: 2018-10-03

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Tensile Testing on FFTF Irradiated Fast Reactor Cladding

**Nuclear Technology
Research and Development**

***Prepared for
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Campaign or Program
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9/30/2018
NTRD-FUEL-2018-000092***



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SUMMARY

This report covers the first tensile tests on samples oriented perpendicular to the extrusion direction on the FFTF irradiated ACO3 duct, and comparison to similar dose samples oriented in the extrusion direction. Control tests were performed to test the same orientation dependency in control lots of HT9 material. This report also presents data from a recently obtained a cold FFTF HT9 duct and compares its tensile properties to a previously used ACO3 archive control lot. Finally, comparison studies of different thicknesses of SSJ type tensile samples were performed.

TENSILE TESTING ON FFTF IRRADIATED FAST REACTOR CLADDING

1. INTRODUCTION

This report details the tensile testing of HT9 material irradiated as part of the ACO3 duct in the Fast Flux Test Facility (FFTF), along with associated cold tests from both ACO3 archive material and material from a newly available HT9 unirradiated duct (MFF8) = the Cold FFTF Duct - that was fueled, but never inserted in the FFTF. This duct adds a crucial new source of HT9 control material that is similar to the ACO3 source material. The original ACO3 archived control material has been almost completely consumed. New comparisons between extrusion (rolling) direction and perpendicular directions are made, along with comparisons between thin and thick samples and control materials from different lots. This data adds to the extensive testing of irradiated HT9 material from the ACO3 duct [1] as well as various other irradiation experiments.

2. Samples

Results from four separate sets of HT9 samples are presented here. All tensile samples were machined to the SS-J2 aka S-1 dimensions seen in figure 1. Thickness of most samples were nominally 0.75mm. Original ACO3 duct irradiated extrusion direction samples were wire-cut Electrical Discharge Machined (EDM) at the Sigma facility in LANL, as reported previously [1]. Rolling direction and perpendicular samples from the unirradiated plate of the archived ACO3 lot of HT9 were also EDM'd at LANL. The perpendicular direction irradiated samples were EDM machined from the ACO3 "A" plates at BWTS in Lynchburg Virginia as part of a Terrapower/DOE joint re-irradiation in the Bor-60 reactor at the RIAR laboratory in Dimotrovgrad, Russia. These perpendicular samples were placed to utilize space below where compression samples had been previously machined. Figure 2 and 3 show the cut plans for plate 5A and 6A. Samples from location 5AC and 6AC were tested, specifically samples 5ACB, 5ACE, 6ACB and 6ACE (Figure 4). Finally, samples were EDM machined from plate 3 from the unirradiated HT9 Cold FFTF Duct (MFF8) (Figure 5) from both the extrusion and perpendicular directions, samples from this duct were machined in both nominal 0.75mm and 0.5mm thicknesses.

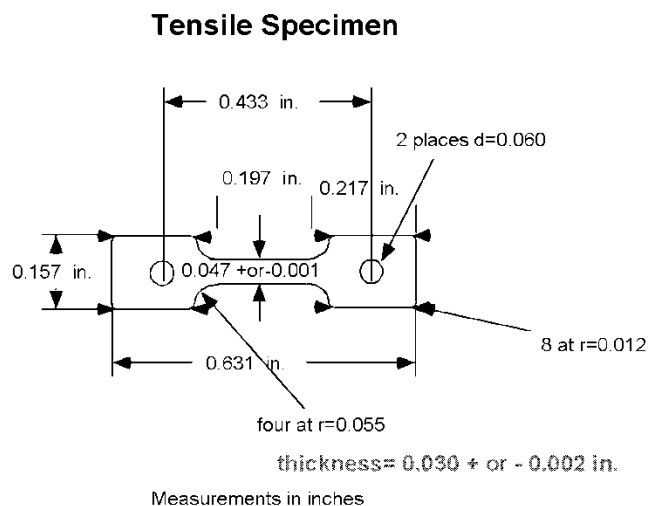


Figure 1, Geometry of S-1 Tensile specimen, most specimens were .75mm (.030") but some of the cold duct samples were cut to 0.5mm (.020").

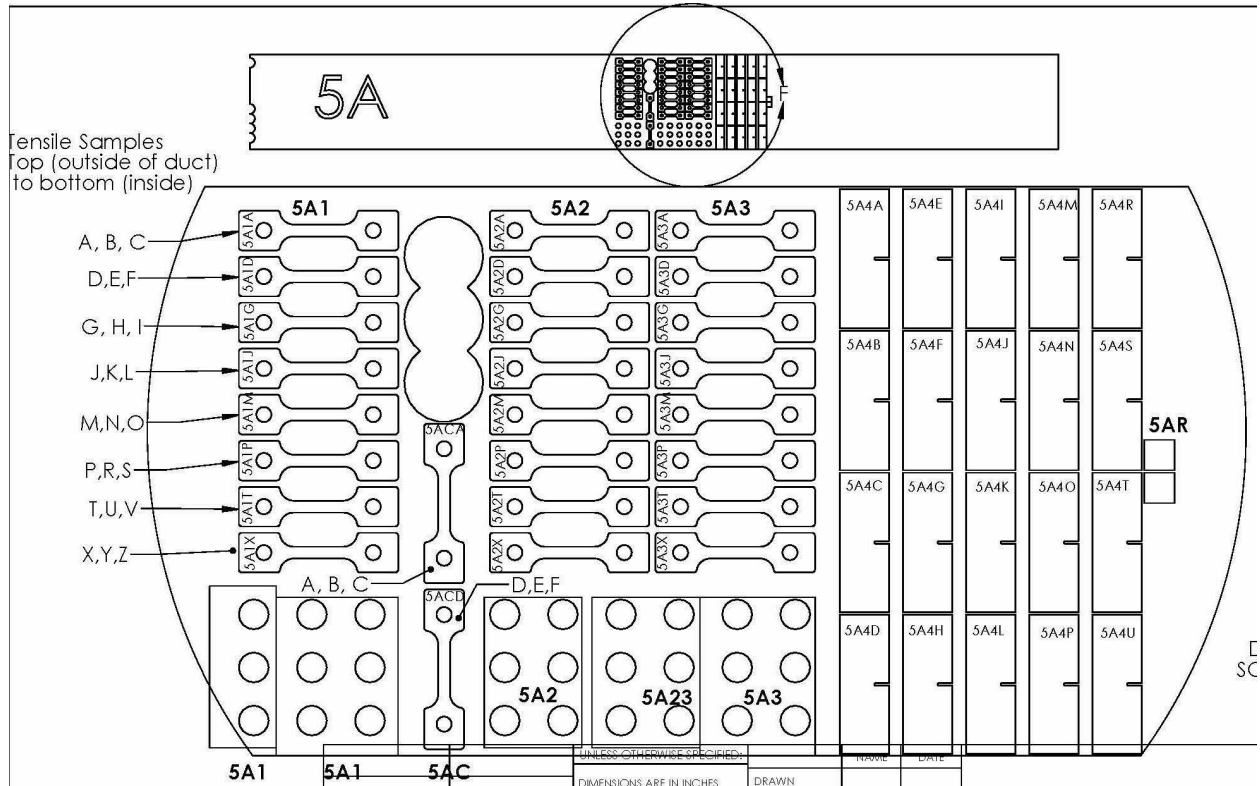


Figure 2. Cut plan from plate 5A of the ACO3 duct. Samples tested were from location 5AC

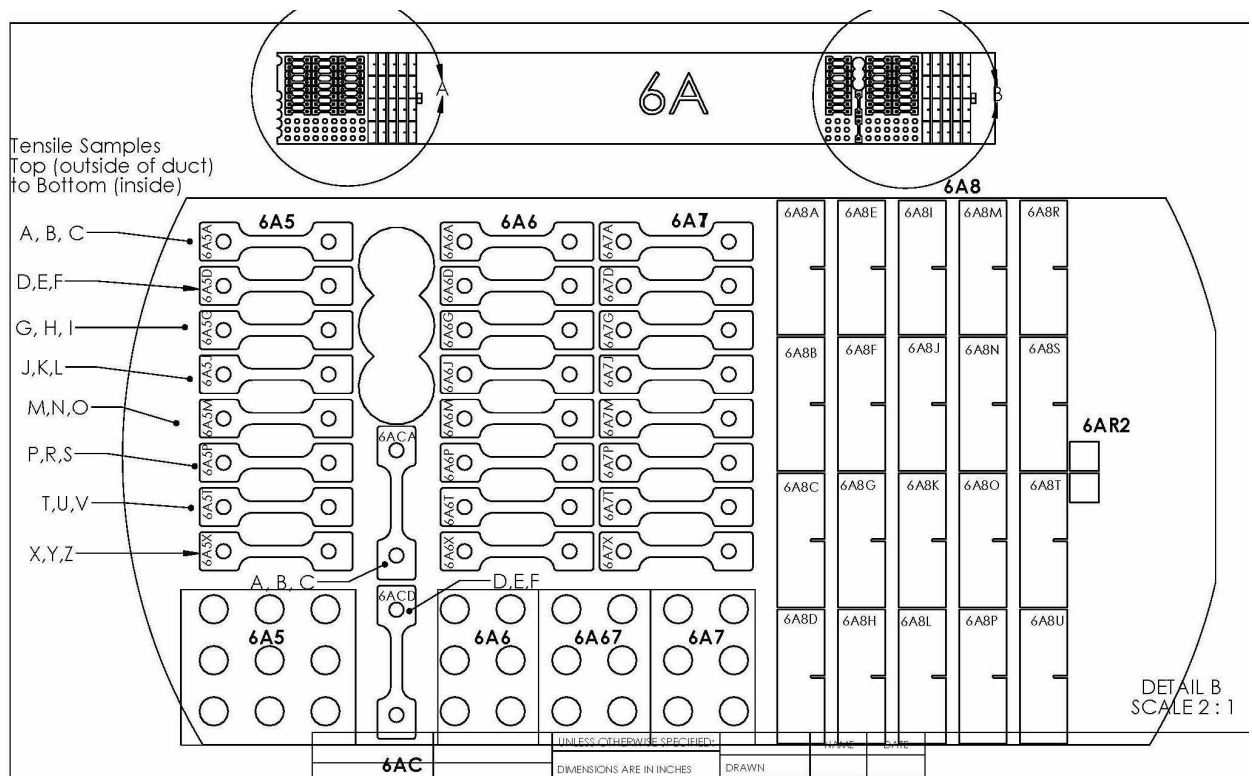


Figure 3. Cut plan from plate 6A of the ACO3 duct. Samples tested were from location 6AC

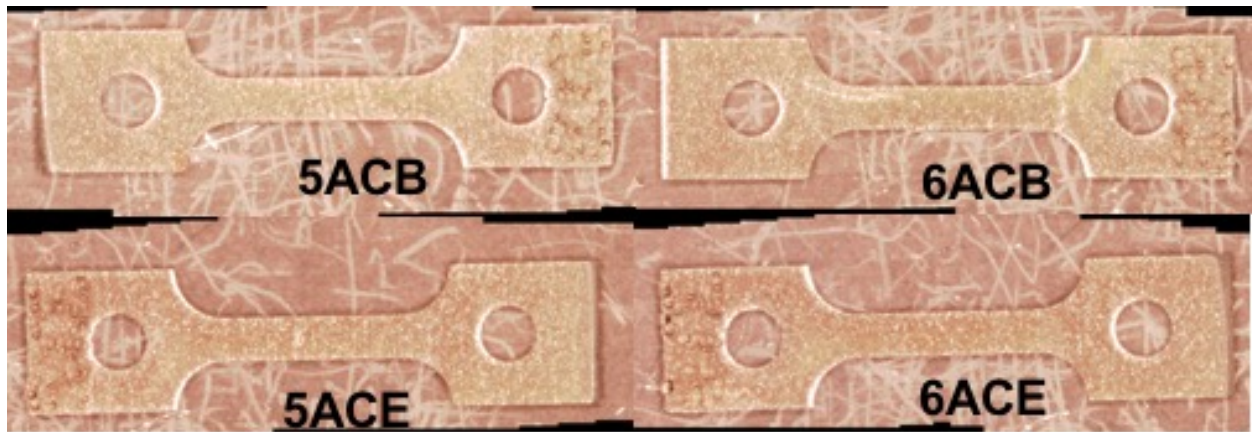


Figure 4. *Samples tested from the perpendicular direction of plates 5A and 6A from the ACO3 duct.*

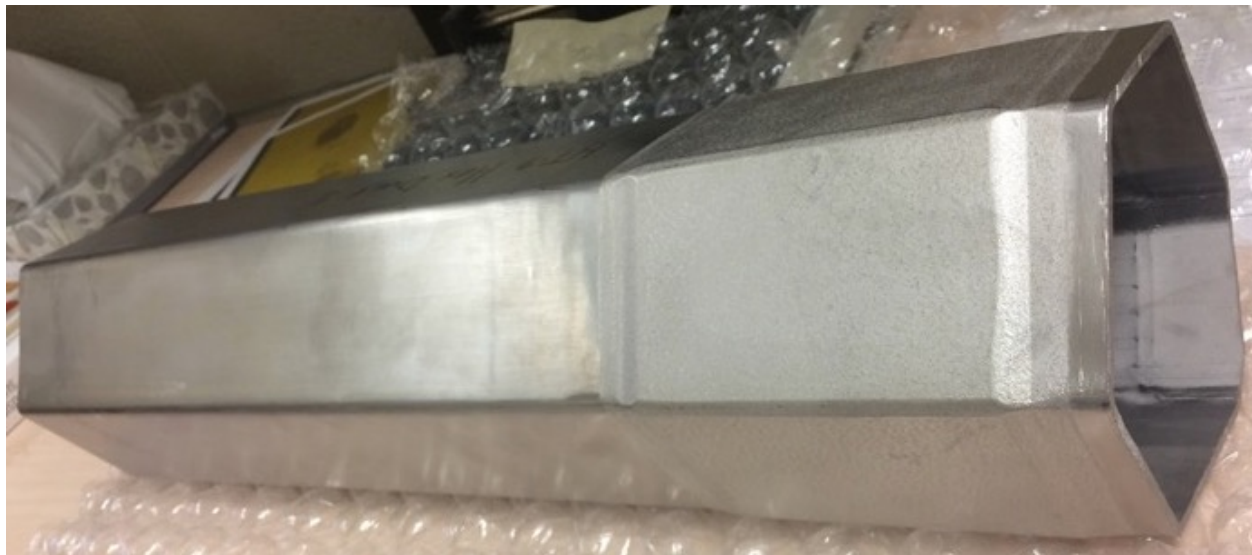


Figure 5. *HT9 Cold Duct MFF8 before machining.*

3. Testing Conditions

Samples were tested on a 30 kN capacity Instron 5567 screw driven load frame located inside a hot cell in Wing 9 at the CMR facility at Los Alamos National Laboratory (Figure 6). The load frame is outfitted with an inert atmosphere furnace operable to 700 °C. Samples were loaded using manipulators into a set of ball ended grips in a shoulder loading fixture (Figure 7). Older tests used a pin loaded fixture, seen in previous reports [1]. Tests were performed at a constant cross head velocity of 0.15 mm/minute corresponding to a nominal engineering strain rate of 5×10^{-4} /sec. Load/displacement data were converted to engineering stress/strain data using the initial measured specimen dimensions. The compliance from the test system was mathematically removed from each curve.

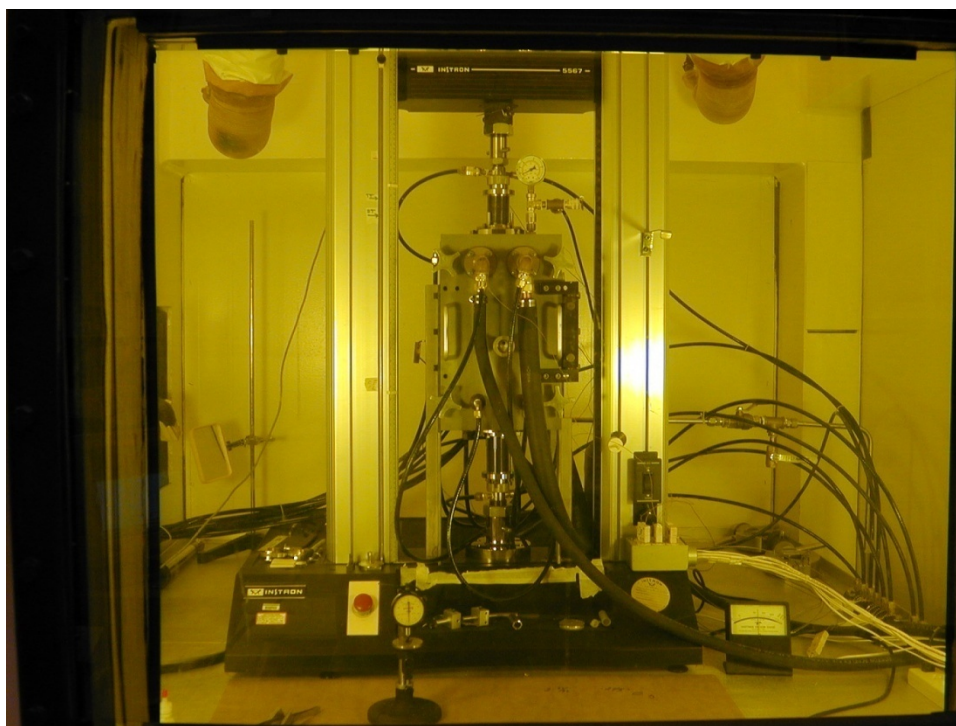


Figure 6 Instron 5567 Load Frame, located in a hot cell at the CMR facility.

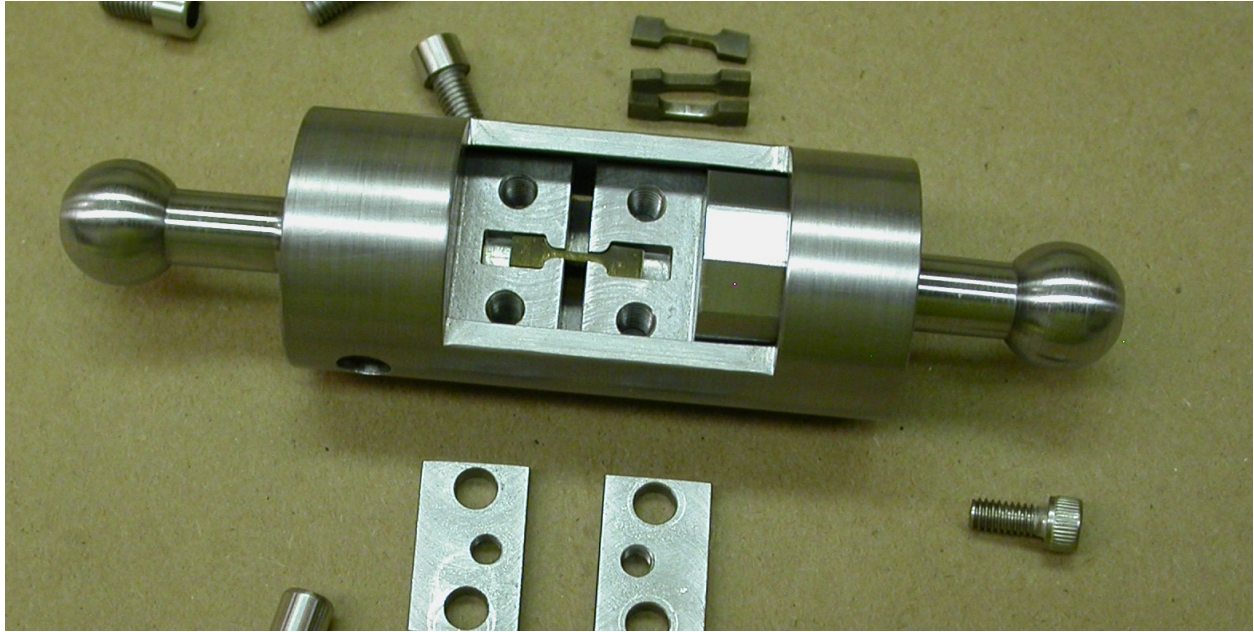


Figure 7- *Ball end tensile grips for shoulder loading samples with or without center hole.*

4. Results

Table 1 below summarizes all results from this experiment. Data is arranged to compare extrusion direction samples to perpendicular oriented samples for irradiated samples, while control samples are grouped by sample direction to compare differences between archived HT9 ACO3 control material in plate form, and HT9 from the cold duct. Thinner samples are noted in blue.

Table 1. Data from irradiated and control tensile tests.

Sample	Material	Source	Direction	Dose	Temp	Yield	UTS	Uniform Elongation	Total Elongation	Thickness
				dpa	C	Mpa	Mpa	%	%	mm
5ACB	HT9	ACO3	Perp	147	440	655	820.6	7.5	16.5	0.758
5ACE	HT9	ACO3	Perp	147	440	645	818.6	7.9	16.9	0.757
5 E 1 - 1	HT9	ACO3	extrusion	147	441	674	861	6.91	16.3	0.821
5 E 1 - 2	HT9	ACO3	extrusion	147	441	656	832	7.52	16.9	0.762
6ACB	HT9	ACO3	Perp	26	385	1030	1080.7	3.4	11.6	0.764
6ACE	HT9	ACO3	Perp	26	385	1020	1068.2	3	11.1	0.767
6 E 9 - 1	HT9	ACO3	extrusion	22	381	1028	1063	1.97	10	0.765
6 E 9 - 2	HT9	ACO3	extrusion	22	381	1036	1080	2.23	10	0.811
Control1P	HT9	Cold Duct	Perp	-	-	615	784.1	7.6	23	0.745
Control2P	HT9	Cold Duct	Perp	-	-	605	777.3	8.2	22.5	0.74
Control3Pthin	HT9	Cold Duct	Perp	-	-	635	784.6	5.6	13.8	0.415
Control4Pthin	HT9	Cold Duct	Perp	-	-	640	792.9	6.8	14.7	0.41
ACO3Control#3Perp	HT9	ACO3	Perp	-	-	632	814	7.43	20.2	0.721
ACO3Control#4Perp	HT9	ACO3	Perp	-	-	643	840	7.55	21.4	0.725
Control1R	HT9	Cold Duct	extrusion	-	-	595	773	7.1	24.5	0.738
Control2R	HT9	Cold Duct	extrusion	-	-	580	752	8.5	25	0.745
Control3Rthin	HT9	Cold Duct	extrusion	-	-	610	763	9	17.7	0.46
Control4Rthin	HT9	Cold Duct	extrusion	-	-	598	748	9.8	18.7	0.43
ACO3Control#1Par	HT9	ACO3	rolling	-	-	548	793	8.58	22.95	0.735
ACO3Control#2Par	HT9	ACO3	rolling	-	-	500	791	8.4	23.1	0.743

The tensile behavior between control and irradiated specimens can be seen in Figure 8, with extrusion and perpendicular comparisons. It is clear that regardless of sample orientation, there is hardening and loss of ductility in the low temperature irradiated samples compared to the higher temperature irradiated samples. The high temperature irradiated samples (~440C) only mildly hardens compared to the controls. This is to be expected, as irradiation temperatures above 400C can anneal out much of the radiation damage. There is a notable loss of overall ductility between the 440C samples and the controls, but uniform elongation is quite similar. Figure 9 displays the perpendicular and extrusion direction samples at similar irradiation conditions. Overall the behavior is extremely similar in both hardening and ductility between the two directions. There is a slight increase in ductility in the perpendicular samples, most likely due to work hardening during the extrusion process. None of the differences between similar irradiation conditions are that large. This speaks to the consistency of the irradiation conditions at the same linear distance from the above core load pad (ACLP), regardless of radial position. Plate A and E are neither adjacent nor opposite faces of the duct, but are separated by one face, the F plate.

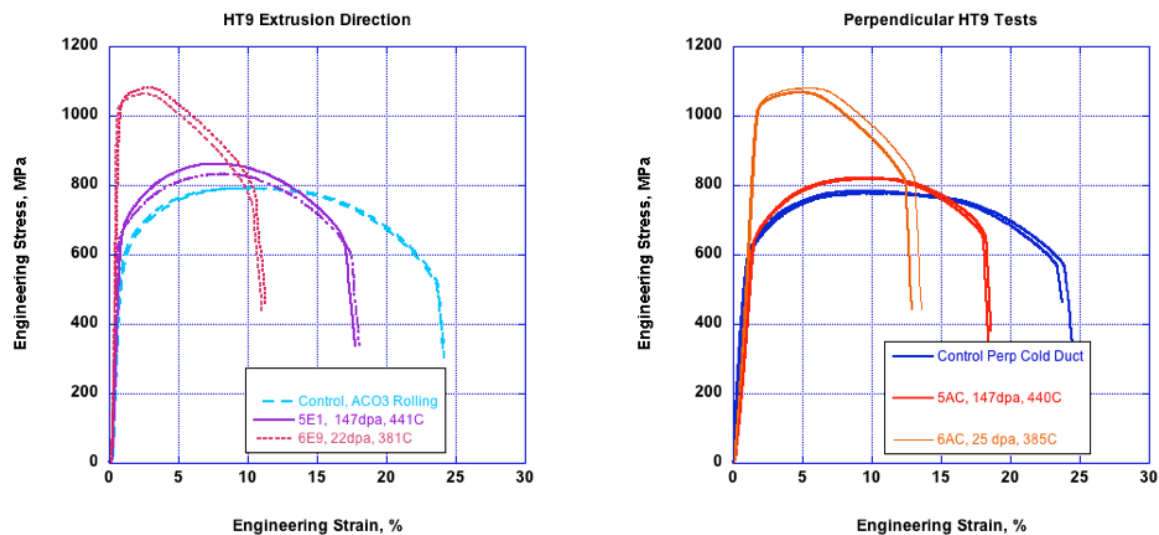


Figure 8 Control and irradiated ACO3 duct tensile data in the extrusion direction (left) and in the perpendicular direction (right).

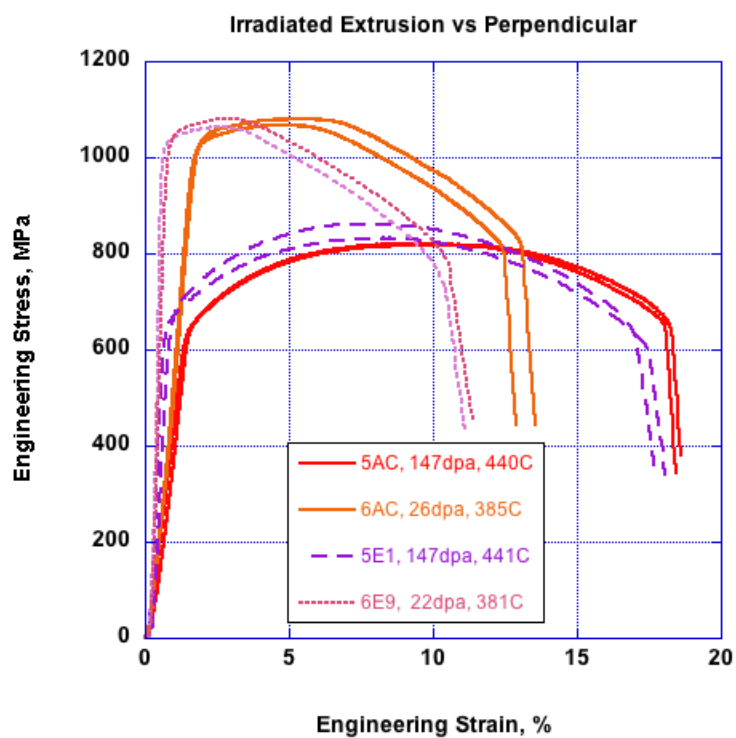


Figure 9 Comparison in the tensile properties of the irradiated ACO3 duct between the extrusion direction (dashed lines) and perpendicular direction (solid lines)

Similar comparisons from the control material can be made, as seen in Figure 10. Here we see extrusion and perpendicular samples compared for both the archived ACO3 control lot of material and the Cold FFTF Duct. There is a small increase in yield and UTS for the perpendicular samples for both sources of control samples. Overall, the results are fairly consistent regardless of sample direction. Figure 11 compares the behavior in each direction between the ACO3 control material and the Cold Duct. The ACO3 control material exhibits slightly higher yield and UTS than the Cold Duct, and slightly less total elongation. These differences may be due to the processing path resulting in a rolled plate (ACO3 control) and an extruded duct (Cold FFTF Duct). However, the differences are very slight, and the Cold Duct appears to be an excellent control material for the irradiated ACO3 duct.

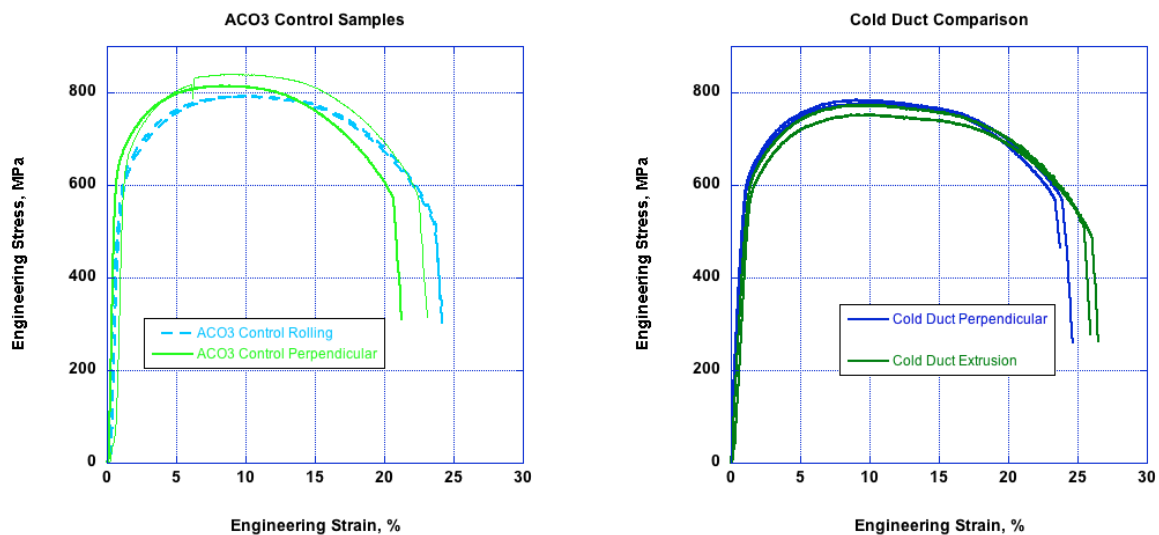


Figure 10 Comparison of tensile properties of control samples in the extruded/rolling direction and the perpendicular direction for the ACO3 control plate (left) and the FFTF Cold Duct (right)

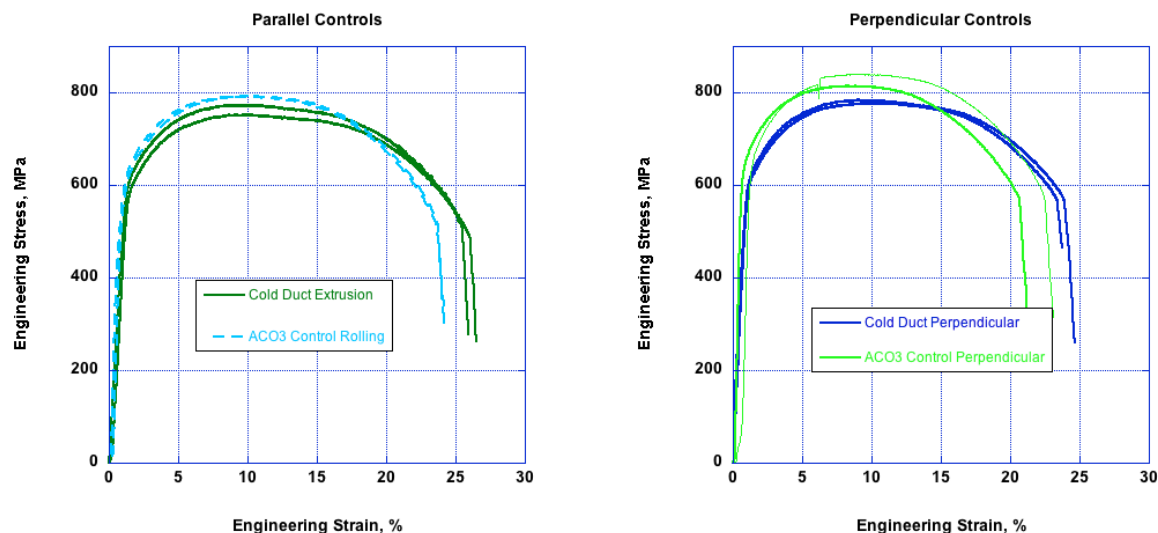


Figure 11 Direct comparison between the ACO3 control plate and the FFTF Cold Duct in the extrusion/rolling direction (left) and the perpendicular direction (right)

Finally, figure 12 shows a comparison between samples that were machined at nominal 0.75mm and 0.5mm thicknesses out of the Cold Duct, in both extrusion and perpendicular directions. The nominal 0.5mm samples came out closer to 0.4mm as machined in most cases, which may amplify the differences. While the yield, UTS and uniform elongation is relatively similar between the thin and thick samples, the total elongation is greatly reduced for the thin samples. This is notable as SSJ type samples are often machined in both 0.75mm and 0.5mm versions, but rarely both in the same irradiation. This merits more study to see how these thickness effects translate to the irradiated conditions.

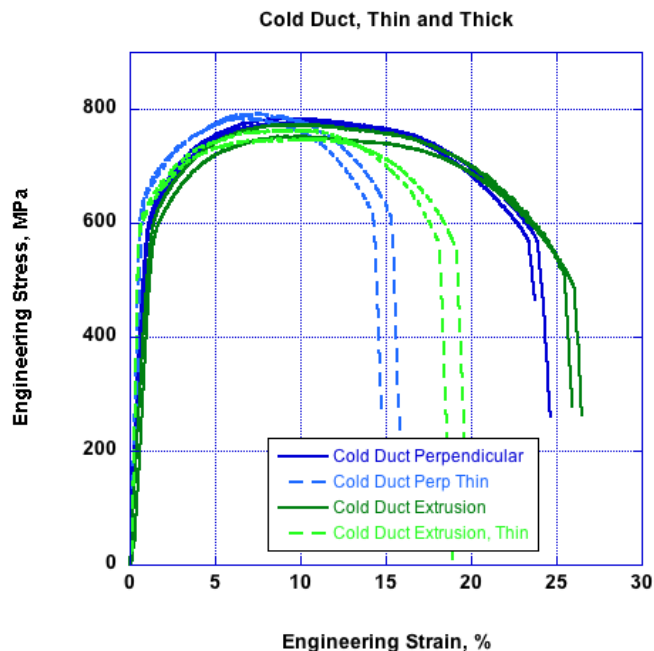


Figure 12 Comparison of thin (dashed) and thick (solid) sample tensile properties from both the extrusion and perpendicular directions of the FFTF Cold Duct.

5. Conclusions and Future Work

This work presents a small but important addition to the large volume of data collected on high dose fast reactor irradiated HT9 material. This is the first irradiated data collected perpendicular to the extrusion direction in the ACO3 duct. While there are clearly subtle effects due to sample direction, we have shown that the tensile behavior is relatively insensitive to sample direction in both the control and irradiated material. Additionally, we have preliminarily shown that there is little difference in the tensile behavior between plates A and E on the ACO3 duct. More data will be taken from plate A samples to confirm this behavior. We also have shown that the Cold FFTF Duct (MFF8) is an excellent source of control material to compare against the irradiated ACO3 duct. The processing path is presumably the same as the ACO3 duct, thus may be more representative than the ACO3 control archive plate used previously. More research into the provenance and specs of the MFF8 duct is needed. Finally, clear differences in total elongation were shown between the mechanical behavior of two common thicknesses of the SSJ type tensile samples were shown. More work should be done to see if this is exacerbated with radiation damage. Finally, most of the data on this report will be added to an in-process journal paper on the mechanical properties of the ACO3 duct.

6. References

- [1] Summary of tensile testing results for irradiated HT-9 steels from the ACO-3 duct
Saleh, Tarik A ; Maloy, Stuart A ; Romero, Tobias J LA-CP-12-00689 ; 2012